Global Ocean Prediction Using HYCOM

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COMPUTATIONAL ASPECTS OF OCEAN MODELS

- Typical ocean model is 3-D Finite Difference
- Some of the characteristics of a 2-D problem
- Vertical scales much different from horizontal
  - HYCOM $1/12^{\circ}$ fully-global: 4500 x 3298 x 32
- 2-D domain decomposition for SPMD scalability
  - Vertical dimension “on-chip”
    - Often treated implicitly
- Fast surface gravity waves O(100m/s)
  - O(100)x faster than advective and internal gravity wave speeds
  - Separate 2-D sub-problem
  - Split-explicit or semi-implicit time step
- Static load balance based on land/sea mask
  - 20% to 40% efficiency gain from skipping land

LIMITS ON OCEAN MODEL SCALABILITY

- **2-D sub-problem**
  - **2-D Halo exchanges and 2-D global sums**
  - **Relatively little computational work**
  - **Highly dependent on communication latency**
- **3-D sub-problem**
  - **3-D Halo exchanges**
  - **Still relatively little computational work per halo exchange**
  - **Still dependent on communication latency**
- **I/O**
  - **Typically no overlap between I/O and computations (today)**
  - **Need fast synchronous reads and asynchronous writes**
    - **From system (e.g. MPI-2 I/O)**
    - **At user level (e.g. via “coupler”)**

PORTABLE LOW LATENCY COMMUNICATIONS

- **If application programmers could target:**
  - **low latency communication hardware**
  - **low latency portable API**
- **This would:**
  - **Reduce the need to “tune” codes**
  - **Allow scaling to more processors**
  - **Expand the range of practical algorithms**
- **At the high end of the HPC market:**
  - **have memory-based low latency hardware**
  - **no portable API to take full advantage of this**
- **Partitioned Global Address Space languages:**
  - **CAF, Co-Array Fortran**
  - **UPC, Unified Parallel C**
  - **Titanium, based on Java**
- **CAF will be in the next Fortran standard**
  - **MPI is so pervasive that we probably need to mix CAF and MPI**
    - **Implementation dependent**

BIT-FOR-BIT MULTI-CPU REPRODUCIBILITY

- Repeating a single processor run:
  - Produces identical results
- Repeating a multi-processor run:
  - Produces different results
    - Using either OpenMP or MPI
    - e.g. fastest global sum is non-reproducible
  - Unless programmer explicitly avoids non-reproducible operations
- Two levels of reproducibility
  - On the same number of processors
    - Some scalable libraries provide this
  - On any number of processors
    - Only “safe” option for code maintenance
    - Always requires careful programming
    - Can be slower
    - Is required for all operational ocean prediction models (e.g. HYCOM)

HYBRID COORDINATE OCEAN MODEL (HYCOM)

- **Developed from MICOM by a Consortium**
  - **LANL, NRL, U. Miami**
- **Hybrid Vertical Coordinate**
  - **“Arbitrary Lagrangian-Eulerian”, see: Adcroft and Hallberg, O. Modelling 11 224-233.**
  - **Isopycnal in open, stratified ocean**
  - **Terrain-following in shallow coastal seas**
  - **Z-level in mixed-layer and/or in unstratified seas**
  - **Dynamically smooth transition between coordinate systems via the layered continuity equation**
  - **Isopycnals can intersect bathymetry by allowing zero thickness layers (as in MICOM)**
- **Open Source ocean model**
  - **Greatly increases size of user community**
  - **Result is more capable and better tested model**
  - **http://www.hycom.org**

OCEAN PREDICTION USING HYCOM

- **Both the Navy (NRL and NAVOCEANO) and NOAA (NCEP) have selected HYCOM for their next generation of Ocean Nowcasting and Prediction systems**
- **See "Ocean Prediction" at http://www.hycom.org**
  - **NRL has run an 1/12° (7 km) Atlantic testbed weekly since 2003**
  - **NOAA is operational daily in Atlantic with 4km near-US resolution**
- **Navy operational system will be 1/12° (7 km mid-latitude) fully global, including a coupled sea-ice model (LANL's CICE)**
  - **Ocean array size: 4500 x 3298 x 32**
  - **Runs on 784 processors (IBM P655+)**
  - **Per model month:**
    - **Run time: 21-23 wall hours**
      - **19-20 wall hours on 714 Cray XT3 cpus**
    - **Daily fields: 525 GB (250 GB compressed)**
  - **Ocean nowcast and prediction now runs daily**
    - **Transitioned from R&D at end of FY07**

DATA HANDLING

- **Data (model output) handling is an often overlooked issue**
  - **Huge data sets**
  - **Moving between compute engine and archive**
  - **Size of long term archive**
- **We try to do as much post-processing as possible as soon as the model run completes**
  - **Before moving data to the archive system**
  - **Different computational needs**
    - **Fewer processors, more memory per processor**
  - **Single system with two kinds of nodes, or two systems with a shared file-system**
- **Can't do post-processing on a Cray XT3**
  - **Move all files across network from ERDC to NAVO**
    - **Post-process on IBM P655+ at NAVO**
    - **Archive at NAVO**
  - **Transfer about 300 GB per wall day**

DOMAIN DECOMPOSITION

- **Split the domain into contiguous sub-domains**
  - **Size each sub-domain for equal work and minimal connectivity to other sub-domains**
- **Add a “halo” or “ghost cells” around each sub-domain such that:**
  - **If the halo is up to date:**
    - **Sub-domain operations are independent**
      - **Only using sub-domain and halo values**
- **Domain is distributed across the processors**
  - **Program only has memory for one sub-domain plus its halo**
- **Land can be a large fraction of the total grid**
  - **Primary reason for different domain decomposition strategies in ocean models**
  - **Affects efficiency, not scalability**

EQUAL-SIZED RECTANGULAR TILES

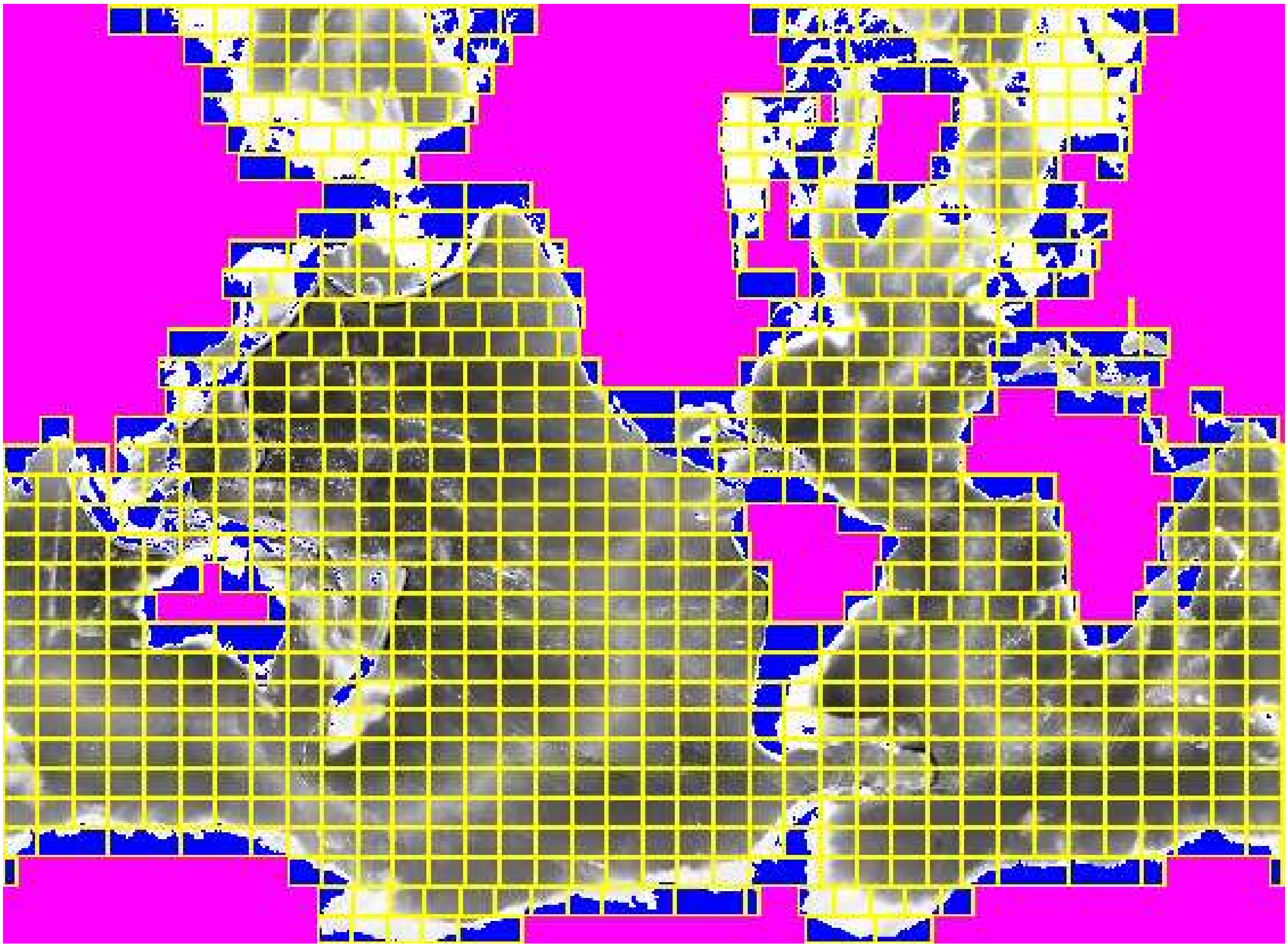
- **Simplest scheme is equal-sized rectangular tiles**
  - **Each tile has four neighbors**
    - **Eight neighbors including halo corners**
- **Overall speed controlled by slowest tile**
  - **Probably have an “all ocean” tile**
    - **no advantage to avoiding land within a tile**
- **So, discard tiles that are entirely over land**
  - **Relatively simple to implement**
  - **Does not discard all land**
  - **Better for large tile counts**
  - **Ineffective on very small tile counts**
  - **MICOM and NLOM**

HYCOM'S DOMAIN DECOMPOSITION

- **Decompose each axis separately**
  - **Still get rectangular tiling**
  - **All tiles in same row are equal height**
  - **Two East-West neighbors**
  - **Many North-South neighbors**
- **Modified equal-area tiling**
  - **Discard all-land tiles**
  - **Shift tiles to fit coastline**
  - **Double-up tiles if less than half ocean**
    - **must avoid land within the tile**
  - **Compared to equal-area tiling:**
    - **Up to 2x the memory requirement**
    - **More expensive halo exchange**
    - **Often significantly fewer tiles**
- **6-element wide halo**
  - **halo is "consumed" over several operations**
  - **reduces the number of communication steps**

MODIFIED EQUAL AREA TILING

36x32 = 1152 Tiles but only 781 Active
10% fewer than equal area tiling



Fully Global “Tripole” Grid
Logically rectangular, but with a special halo exchange for the Arctic bi-polar patch

SCALABILITY TEST

- Explore scalability to 2,000 processors, of:
  - 1/12° Global HYCOM (4500x3298x26)
    - In DoD TI-0X benchmark suites
      - Target of suite is 256 cpus
    - A DoD Challenge project configuration
- Benchmark code “frozen” in 2000
  - Use a recent HYCOM source code
- Benchmark run shorter than the typical run
  - Ignore the start-up time before the first model time step

INITIAL SCALABILITY TESTS

- **On NAVO's kraken (IBM P655+):**
  - **Total I/O time is 88 to 96 seconds**
  - **Without I/O the 1006 to 2040 speedup would be 1.74x**
  - **On 2040 cpus 15% of the time is I/O**

MPI TASKS	NODES	WALL-TIME	SPEED-UP
504	63	1515.1	
1006	126	946.9	1.60x 504
2040	255	587.2	1.61x1006

- **On ARL's jvn (Linux Networx Xeon Cluster):**
  - **Total I/O time is 284 to 336 seconds**
  - **Without I/O the 1006 to 2040 speedup would be 1.84x**
  - **On 2040 cpus 35% of the time is I/O**

MPI TASKS	NODES	WALL-TIME	SPEED-UP
504	252	1867.0	
1006	503	1209.2	1.54x 504
2040	1020	772.1	1.57x1006

SCALABILITY TEST ON CRAY XT3 AND IBM P575+

- **On ERDC's sapphire (Cray XT3)**
- **Slightly different test case, similar I/O needs**
  - **Total I/O time is 280 to 310 seconds**
  - **Without I/O the 1006 to 2040 speedup would be 1.97x**
  - **On 2040 cpus 34% of the time is I/O**
- **Lustre file-system performs similarly on JVN and sapphire**

MPI TASKS	NODES	WALL-TIME	SPEED-UP
504	504	2321.9	
1006	1006	1403.8	1.65x 504
2040	2040	841.6	1.67x1006

- **On NAVO's babbage (IBM P575+)**
  - **Total I/O time is 22 to 24 seconds**
  - **On 2040 cpus only 4% of the time is I/O**

MPI TASKS	NODES	WALL-TIME	SPEED-UP
504	504	2144.0	
1006	1006	1165.2	1.84x 504
2040	2040	694.9	1.68x1006

HYCOM I/O

- **Model is REAL*8, but I/O is big-endian REAL*4**
- **HYCOM does I/O one 2-D array at a time, from the 1st task only**
  - **Each I/O request is 56.6 MB**
  - **Total I/O is about 11 GB**
  - **Total I/O time of 90 seconds is 125 MB/s**
- **Gather onto 1st task was in REAL*8**
  - **REAL*4 gather saved about 20%**
  - **Included in above times**
- **MPI-2 I/O an obvious alternative:**
  - **HYCOM arrays contain "holes" over land**
    - **Must be filled by "data_void"**
    - **MPI-2 I/O allows gaps, but can't fill them**
  - **Do (MPI-2) I/O from one task per row**
    - **On both kraken and jvn**
    - **Speeds up reads, but not writes**
      - **HYCOM does far more writes than reads**

HYCOM I/O - FUTURE ENHANCEMENTS

- **Best solution is user-level asynchronous I/O**
  - **Dedicate enough processors to I/O so that all writes can be buffered**
    - **Size of buffer sets number of processors**
  - **Overlap I/O with computation**
    - **Fast I/O still required, since actual I/O time sets lower limit on wall time**
  - **Plan to implement using the Earth System Modeling Framework (ESMF)**

SUMMARY

- **Low communication latency is one key to good ocean model scalability**
  - **MPI is not a low-latency API**
  - **Co-Array Fortran is a better approach**
- **Bit for bit reproducible global sums are a challenge**
- **I/O is a significant barrier to scalability**
  - **Best solution is user-level asynchronous I/O**
- **Minimize data motion**
  - **Run the model and pre/post processing on:**
    - **Single machine with two kinds of nodes, or**
    - **Two machines with a shared file-system**